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Nordlin, E.F. and Stoker, J.R.

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16. ABSTRACT
This report covers testing performed on a proposed elastomeric energy absorbing and restraining unit designed to restrict movement at the hinge openings of reinforced concrete bridge spans when subjected to earthquake forces.

Although minor modifications were made for each of the five tests conducted, the basic unit consists of 11-3/4" diameter thick walled neoprene tubing contained in a 24" length of 12" diameter extra heavy steel pipe. A steel rod pulls against a 11 1/2" diameter round steel backup plate resting on the neoprene and runs through the center of the pipe and the neoprene tubing. In an installed situation the rod continues on through and is secured on the other side of the hinge. Any excessive force acting to separate the hinge will compress the neoprene by pulling the backup plate through the pipe. The load-deflection characteristics of the restrained neoprene then determines the final amount of movement for the forces involved.

For this testing program the units were loaded throughout the top crosshead of a 1000k MTS testing machine. Load-deflection curves are presented for the five tests.

Compressive load-deflection curves are also presented covering the results of two additional tests on two different configurations of unrestrained rectangular neoprene or elastomeric bearing pads.

The device including the several modifications tested did not provide the necessary energy absorbing characteristics.

No implementation of the device is planned.

17. KEYWORDS
Energy absorber, bridge/structures/hinge, earthquake resistant construction, elastomers

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HIGHWAY RESEARCH REPORT

ELASTOMERIC ENERGY ABSORBER

71-29

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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RONALD REAGAN, Governor

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November 1971

Mr. J. E. McMahon
Assistant State Highway Engineer, Bridges
Bridge Department

Dear Sir:

Submitted herewith is a research report entitled:

ELASTOMERIC ENERGY ABSORBER

Eric F. Nordlin
Principal Investigator

J. R. Stoker
Co-Investigator

Assisted By
J. Jay Folsom
Dale W. Sathre

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

JJF:mw

Attachment

ABSTRACT

REFERENCE: Nordlin, E. F., and Stoker, J. R., "Elastomeric Energy Absorber", State of California, Department of Public Works, Division of Highways, Materials and Research Report 762501-656592.

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Although minor modifications were made for each of the five tests conducted, the basic unit consists of 11-3/4" diameter thick walled neoprene tubing contained in a 24" length of 12" diameter extra heavy steel pipe. A steel rod pulls against a 11½" diameter round steel backup plate resting on the neoprene and runs through the center of the pipe and the neoprene tubing. In an installed situation the rod continues on through and is secured on the other side of the hinge. Any excessive force acting to separate the hinge will compress the neoprene by pulling the backup plate through the pipe. The load-deflection characteristics of the restrained neoprene then determines the final amount of movement for the forces involved.

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INTRODUCTION

During the February 9, 1971, Los Angeles earthquake (6.5 Richter Scale), several reinforced concrete box girder structures separated at the deck span hinges. As a result, it was felt a positive device should be developed to connect the two sides of a hinge together and at the same time act as a shock absorber without interfering with the normal movement at the hinge.

Consequently, early in March 1971 the Bridge Department prepared a research proposal to investigate the possible utilization of various configurations of neoprene tubing to act as a hinge restraining energy absorber unit. On March 22, 1971, the Federal Highway Administration approved the project, to be included in the HPR-PR-1(8) bridge research program for the amount of $10,000 and on April 7, 1971, the Materials and Research Department was authorized $8,000 to fabricate and test approximately ten elastomeric energy absorber units. The project was to be charged to Bridge Department Cost Center 14030 and engineering work authorization 14-624150. A job number of 19601-762501-656592 was assigned by the Materials and Research Department.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

OBJECTIVE

The objective of this project was to investigate and test elastomeric devices which would prevent a bridge from separating at the hinges during earthquakes and at the same time absorb considerable energy.

CONCLUSIONS

To be effective under dynamic loading conditions, a hinge restraining device should be capable of resisting forces in the neighborhood of 300 kips while at the same time limit movement of the hinge to 2 or 3 inches. Ideally the load-deflection characteristics of such a device should exhibit a stress-strain curve of a shape to encompass a large area under the curve; thus indicating the capability of the restraining unit to absorb a considerable amount of energy.

The cylindrical neoprene hinge restrainer units tested under this project do in fact have the capability of sustaining the large design forces, but the shape of the load deflection curve indicates that little energy will be absorbed during the loading operation. Consequently, without the benefit of good energy absorption characteristics, there appears to be no particular advantage to this concept over other subsequently proposed hinge restrainer designs. Therefore, since the devices tested did not provide the energy absorption required to perform adequately in bridge hinges and no further modification to provide this quality could be conceived, the project was terminated after Test No. 7.

HINGE RESTRAINER DESCRIPTION

Although the restrainer for each test was modified to some degree, all units were of the same basic design. The restrainer units appeared similar in shape to a large shock absorber and consisted of end loaded 70 durometer thick walled neoprene tubings restrained by a steel pipe on the outside. Inside restraint generally consisted of a steel rod except for Test No. 5 where a steel inner pipe was used.

Photo No. 1 shows the components of the unit used for Test No. 1 through 5. The holes shown through the walls of the neoprene tubings applied only to Tests 4 and 5. Figure No. 2 details the hole arrangement in the neoprene tubing. Photo No. 4 shows how the components fit together and illustrates the testing procedure utilizing a 1000 kip MTS testing machine.

The cylindrical neoprene absorbing media is the same as that material used commercially for marine fendering. However, for fendering purposes the material is generally unconfined and loaded laterally. The hardness of the neoprene was 70 durometer on the Shore "A" scale.

The restraining steel cylinder as shown in Photo No. 2 was extra heavy ($\frac{1}{2}$" thick wall) 12 in. nominal diameter (11.75 in. I.D.) steel pipe 24 " in length. Tensile tests on the material showed it to have a yield strength of 40.2 kips per in.^{2}. Strain gages were attached to the pipe as shown in Photo No. 3 to monitor hoop strain during the loading operation.

As shown in Photo No. 4, the unit was loaded through a backup plate using a 2" or 2$\frac{1}{4}$" diameter steel rod. When installed in a bridge, this rod acts as the tension connection across the hinge.

In addition to determining the physical properties of the steel restraining unit components, standard Charpy impact tests were also conducted on the 2$\frac{1}{4}$" diameter steel rod. The results of this testing are tabulated in Table 1.

TABLE I

TENSILE AND IMPACT DATA

	Restraining Cylinder	2" Dia. Rod	2$\frac{1}{4}$" Dia. Rod
Ultimate	47.5 ksi	- -	122 ksi
Yield	40.2 ksi	121 ksi	102 ksi
Elongation	40%	- -	21%
Reduction of Area	79%	- -	65%
Charpy Impact Value			94 ft.-lb. @ +71° F.

FABRICATION AND INSTRUMENTATION

The elastomeric energy absorber was fabricated by the Materials and Research Department machine shop. Fixtures were made to restrain the elastomeric energy absorber in the 1000 kip MTS testing machine and protect hydraulic lines, etc. in the event of a premature failure. The restraining cylinder was chamfered on one end to facilitate the installation of the large neoprene tubing, which was badly out of round due to slump during the extruding and/or curing operation. A force of approximately 10 kips was required to push the neoprene into the steel cylinder.

During the unloading cycle of Test No. 1, it was discovered that the steel cylinder would ride up on the neoprene and also that the 1" thick round backup plate was stressed past its yield strength. For subsequent tests steel flanges were welded to the bottom of the steel cylinder and bolted to the testing machine fixture to prevent movement, and the thickness of the backup plate was increased to 1-1/8". As additional insurance against deformation, a small bearing plate was also used on the loading plate (see Photo No. 1).

From coupon tensile tests, it was determined that the restraining cylinder would very likely be the weakest component of the unit. Consequently, the cylinder was instrumented with four strain gages to monitor the hoop-strain in the cylinder. The gages were installed at three levels on the outside of the cylinder, one at the top, two at the center, and one at the bottom.

The theoretical maximum allowable hoop strain was calculated from the tensile data as follows:

$$\text{Strain @ yield} = \frac{\text{stress @ yield}}{E}$$

$$= \frac{40{,}000 \text{ psi}}{30 \times 10^{6} \text{ psi}}$$

$$= 1330 \times 10^{-6} \text{ in./in.}$$

Therefore the maximum reading for a 1" strain gage would be 1330 microinches.

Using the maximum allowable hoop-strain as a limit, the elastomeric energy absorber was loaded to a maximum of 290 kips in Test No. 2. This was well under the 406 kip yield strength of the 2¼" diameter rod.

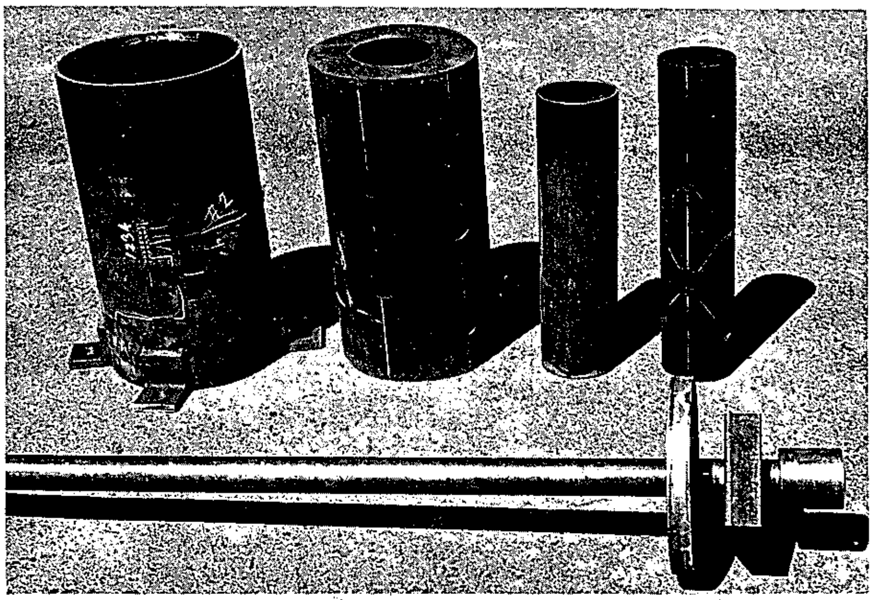


PHOTO NO. 1
ENERGY ABSORBER COMPONENTS
(HOLES IN NEOPRENE FOR TESTS 4 AND 5 ONLY)

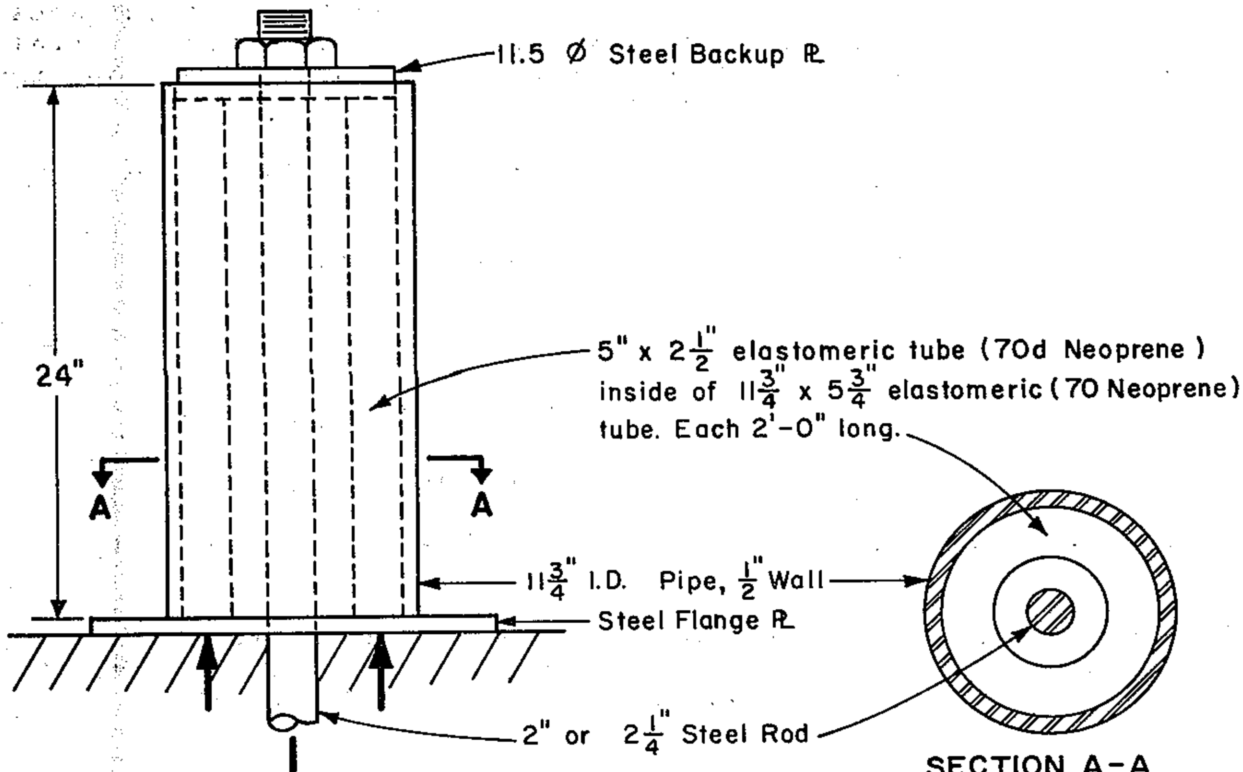


Figure 1

TYPICAL ENERGY ABSORBER

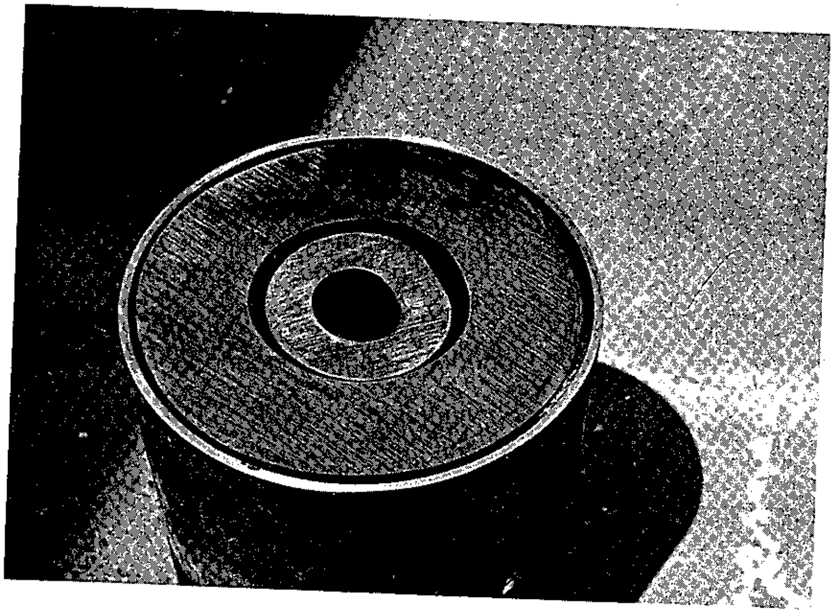


PHOTO NO. 2
NEOPRENE INSTALLED IN CYLINDER

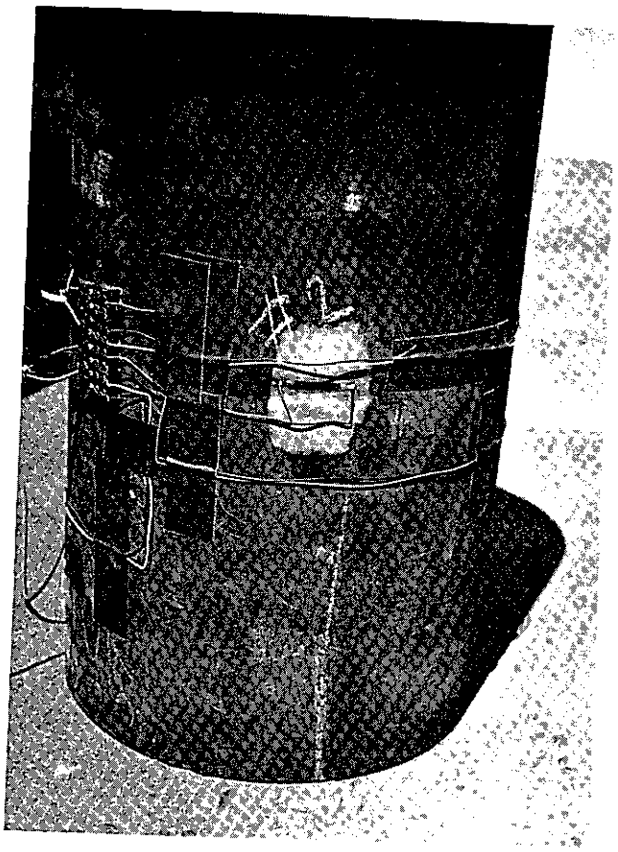


PHOTO NO. 3
STRAIN GAGES

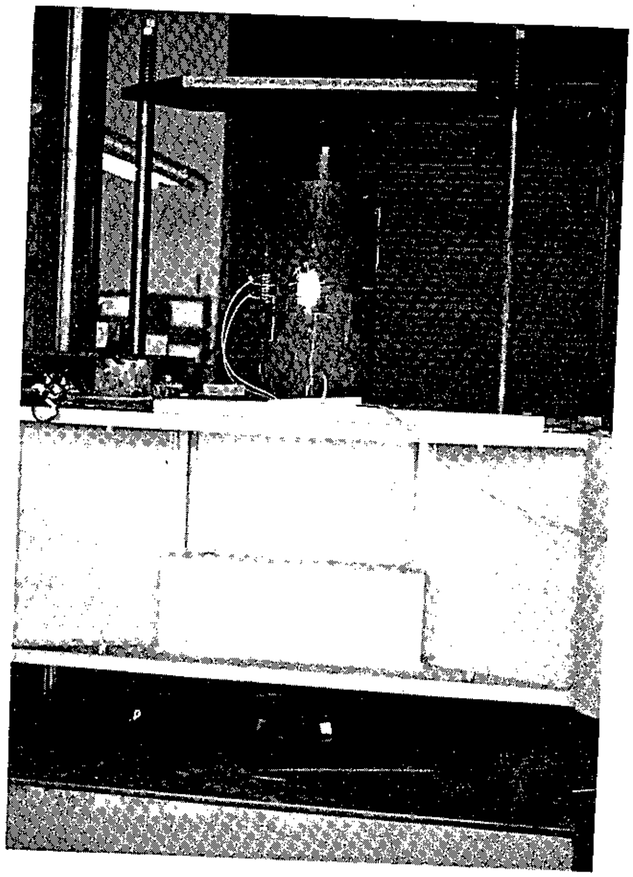
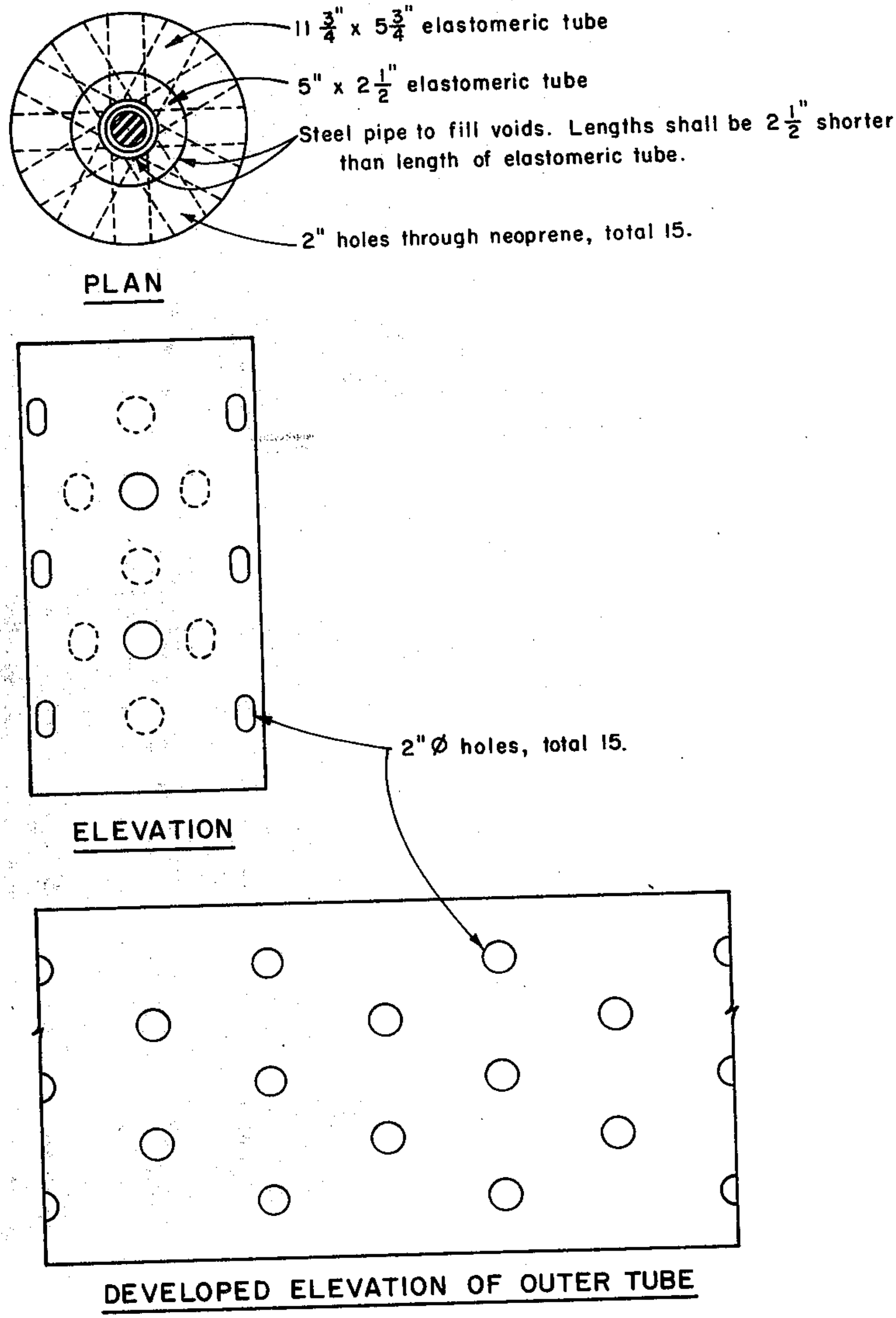


PHOTO NO. 4
TEST MACHINE

Figure 2

ELASTOMERIC ENERGY ABSORBER
(HOLE DETAILS FOR TESTS 4 AND 5)



PRESENTATION OF DATA

Load-deflection curves for the five tests are presented in Figures 3 through 7. The area under the curve is delineated by the shaded area and represents the energy absorbed. A tabulation of results for Test No. 1 through 5 showing maximum load, maximum deflection, and energy absorbed is summarized in Table 2. The details of each test unit are shown by the cross-section and notes on the load-deflection curves.

Test No. 3 was cycle loaded four times; after the initial load the energy absorbing characteristics were reduced by 1/3 due to hysteresis loss in the neoprene.

In Test No. 5 the maximum applied load was only 120 kips because the inside steel pipe restricted the compressive movement of the round backup plate.

Loading rates of 200 kips/min. were programmed into the testing machine and used in all five tests. A constant loading rate was used in an effort to equalize the effect of the creep characteristics of the neoprene.

Although not included in the work plan for this project, two additional compressive load deflection tests were performed on elastomeric material. See Figures 8 and 9 for the curves obtained.

Test No. 6 was conducted on an unrestrained 12" square x 6½" high neoprene fender pad with a 5½" dia. hole in the center. Being unrestrained, this material would only sustain an 80 kip compressive force. Figure 8 includes a sketch of this unit.

Test No. 7 utilized five ½" elastomeric bearing pads (12" x 12") alternately stacked with ½" plywood. A more desirable curve was obtained with this combination except that permanent set was left in the plywood. This unit sustained a maximum compressive force of 300 kips. Figure 9 includes a sketch of this unit.

TABLE 2

SUMMARY OF TEST DATA

Test No.	Max. Load (Kips)	Max. Deflection (in.)	Energy Absorbed (ft./lbs.)	Remarks
1	210	2.9	12,200	Void = 193 in.^{3}
2	290	2.65	10,500	Void = 173 in.^{3}
3	250	1.93	7,800 5,100*	Void = 173 in.^{3} Cycled four times
4	250	3.5	15,600	Void = 173 in.^{3} +15 - 2" dia. holes
5	120**	1.93	7,800	w/inner steel cylinder w/o inner neoprene cylinder
6	80	2.1		Cycle loaded
7	300	1.3		Cycle loaded

* After 1st cycle energy absorption dropped off, neoprene did not return to its original shape.

** Backup plate bottomed out on the inside pipe.

Figure 3
TEST NO. 1

ELASTOMERIC ENERGY ABSORBER

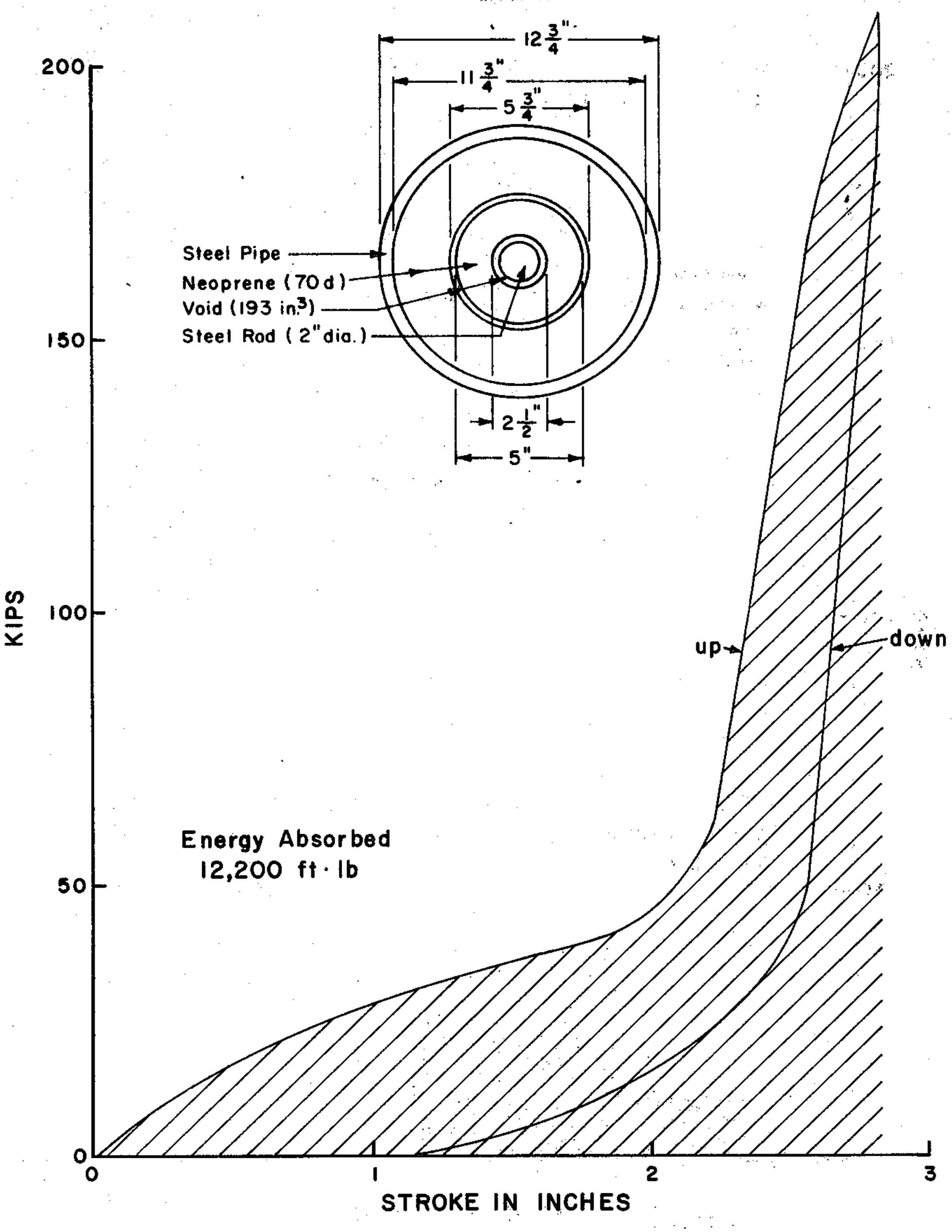


Figure 4
TEST NO. 2

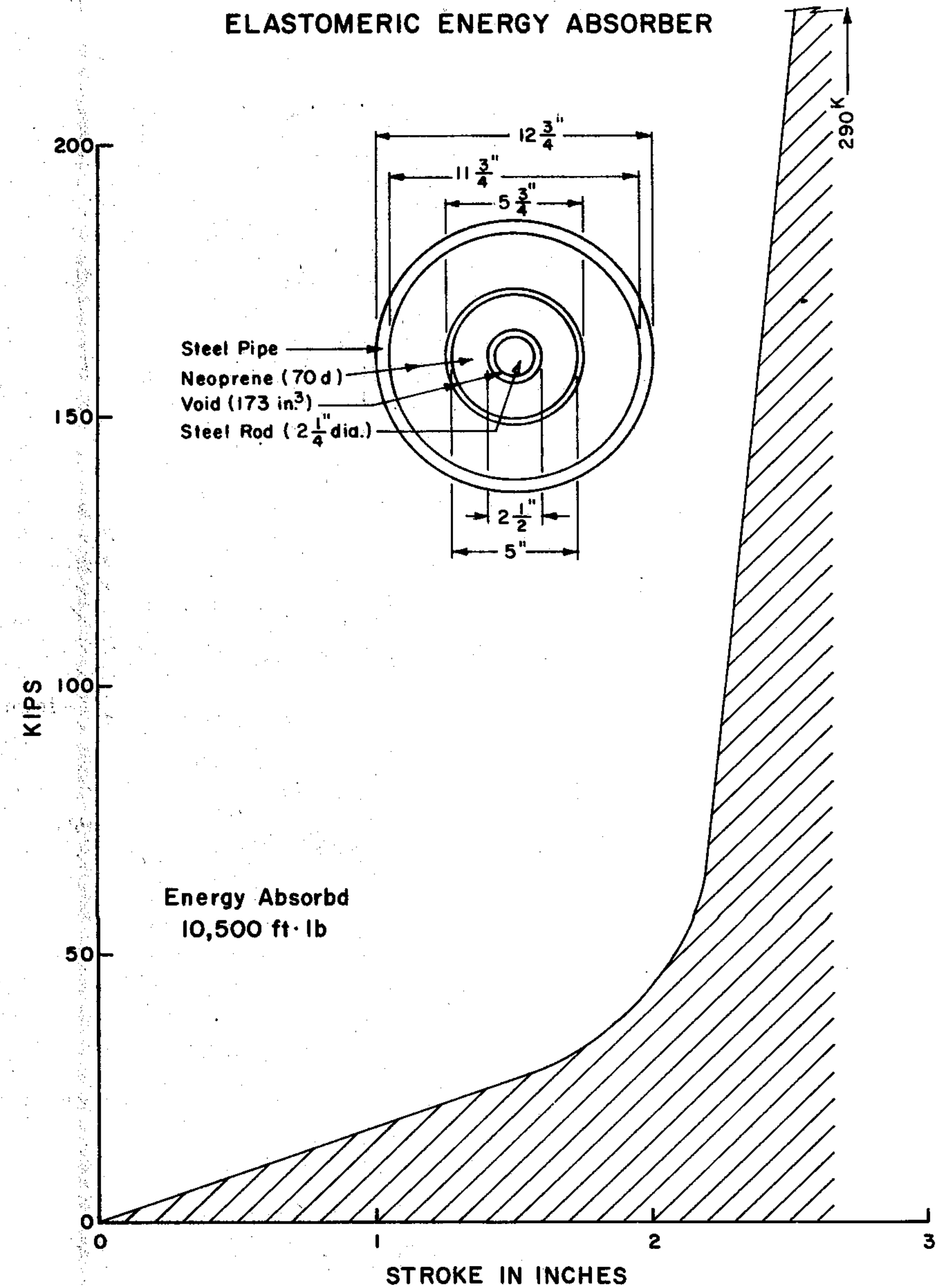


Figure 5

TEST NO. 3

ELASTOMERIC ENERGY ABSORBER
CYCLE LOADING

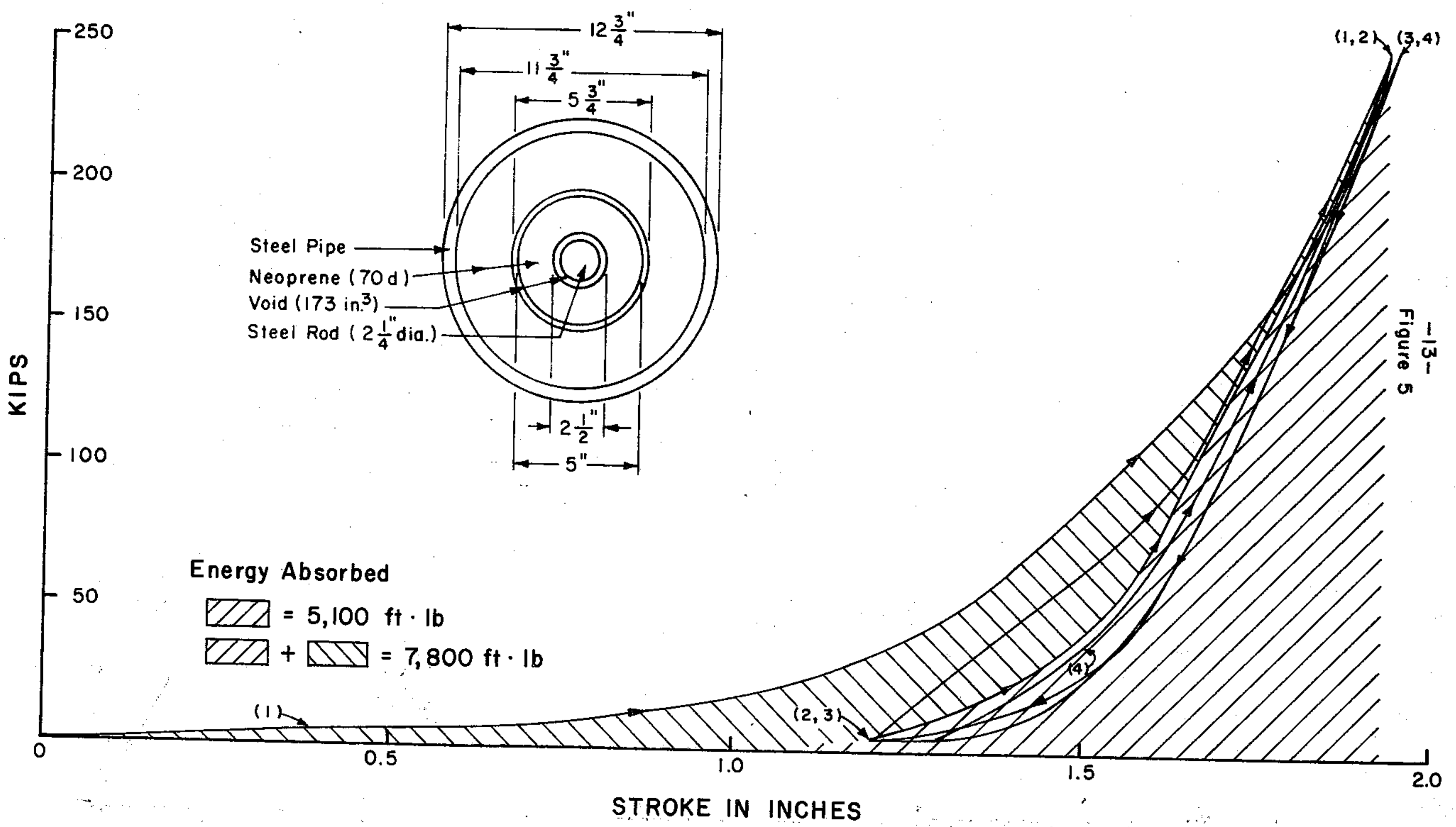


Figure 6
TEST NO. 4

ELASTOMERIC ENERGY ABSORBER

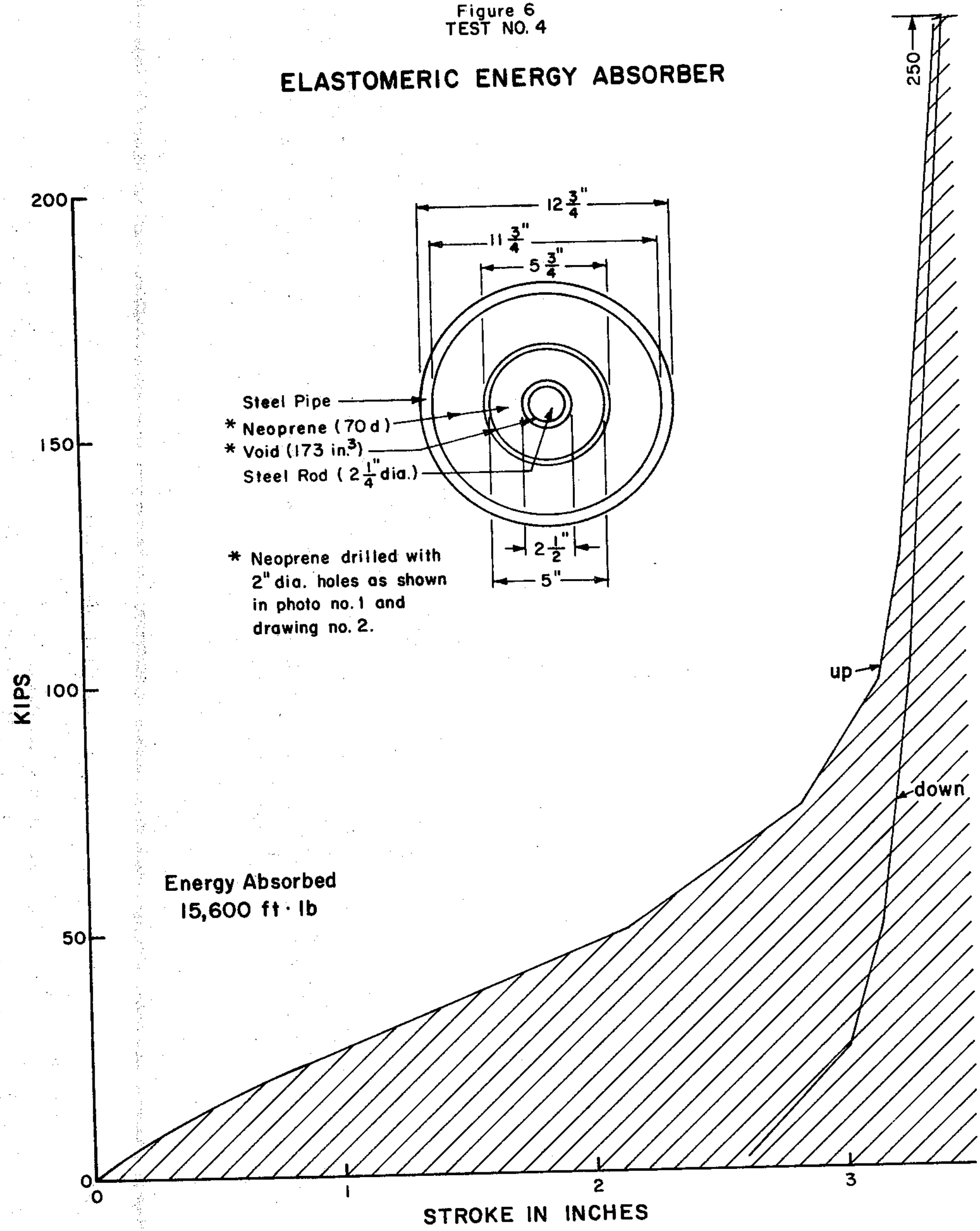
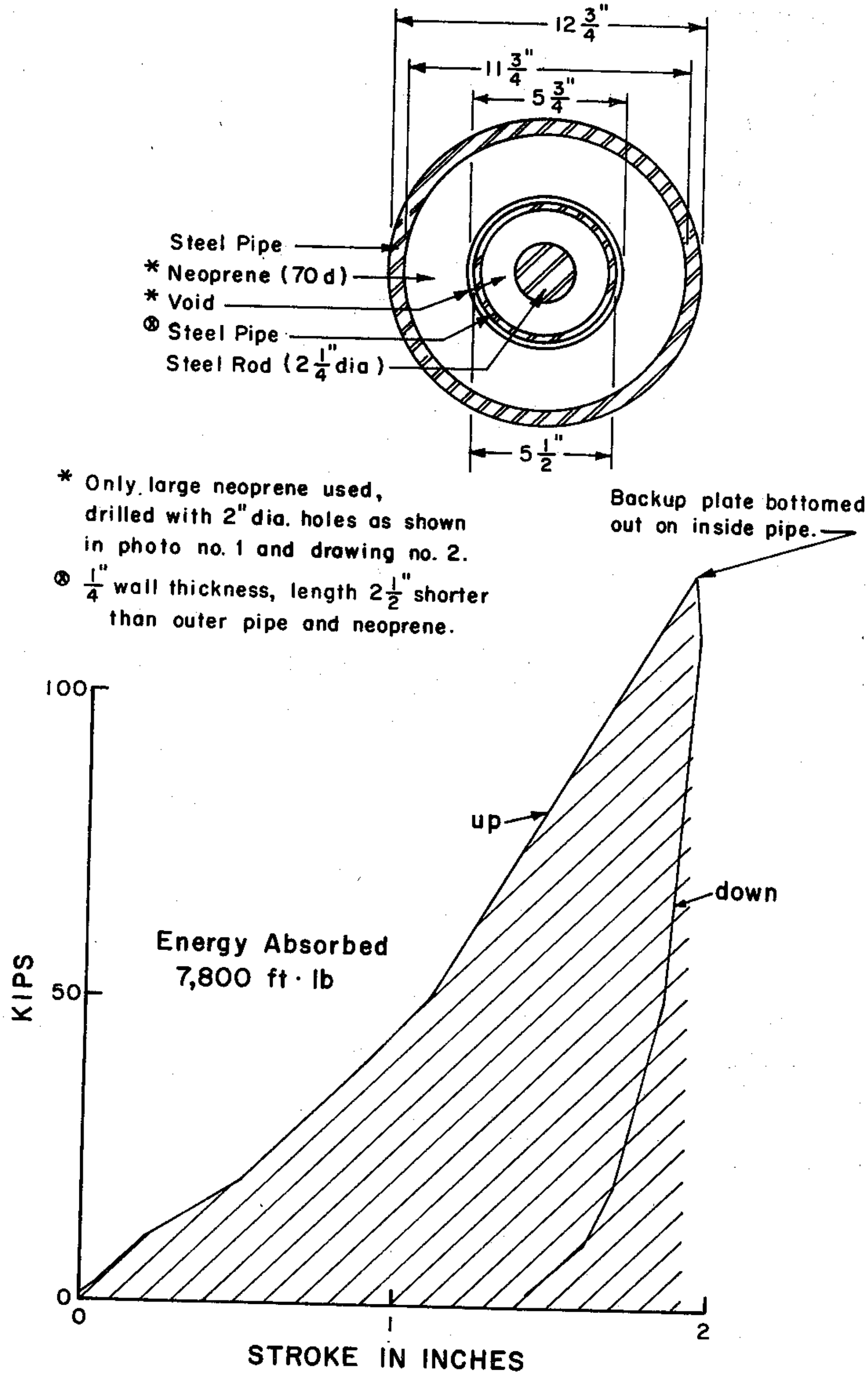


Figure 7
TEST NO. 5

ELASTOMERIC ENERGY ABSORBER



* Only large neoprene used, drilled with 2" dia. holes as shown in photo no. 1 and drawing no. 2.

⊗ 1/4" wall thickness, length 2 1/2" shorter than outer pipe and neoprene.

Figure 8

TEST NO. 6

ELASTOMERIC ENERGY ABSORBER
CYCLE LOADING

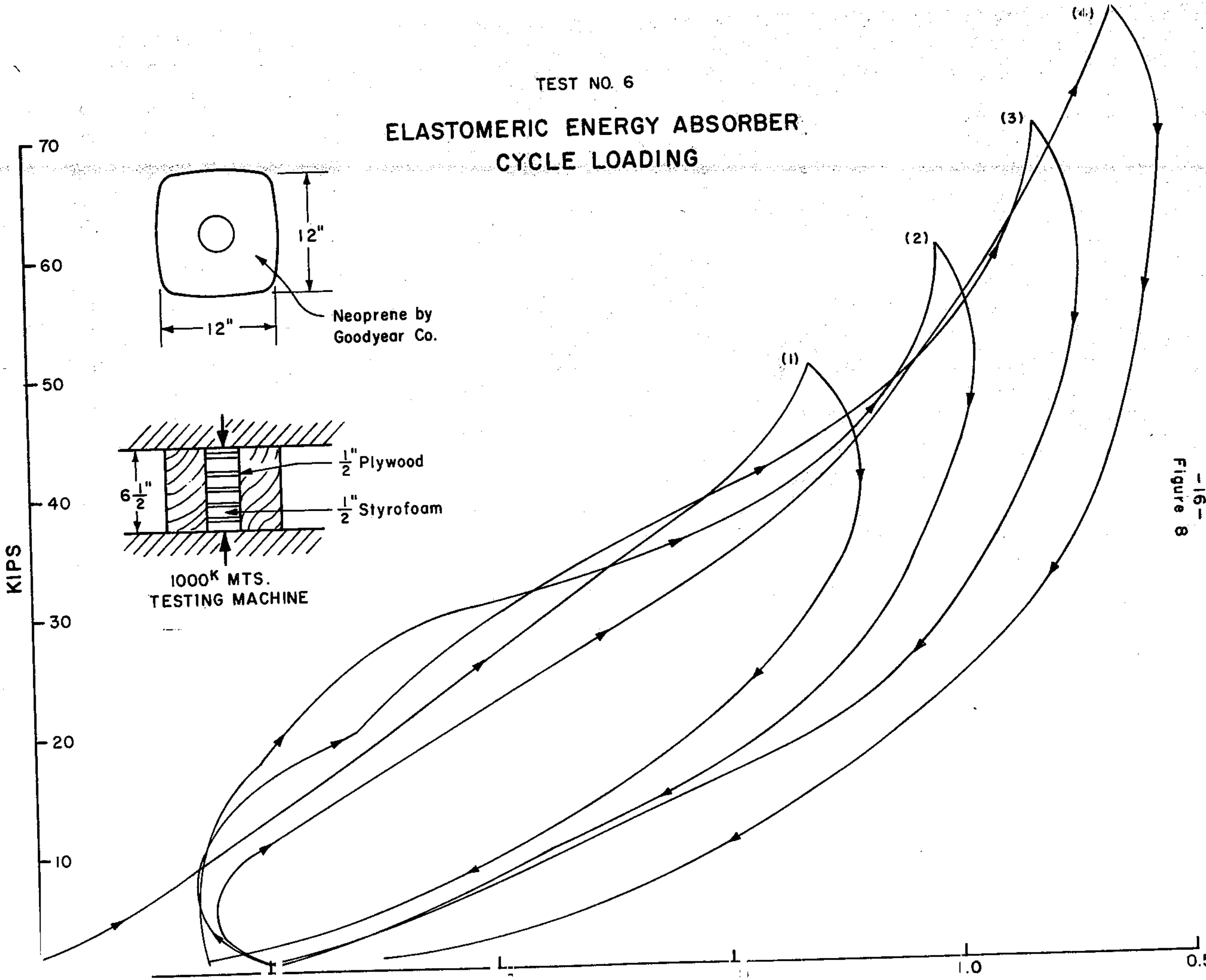
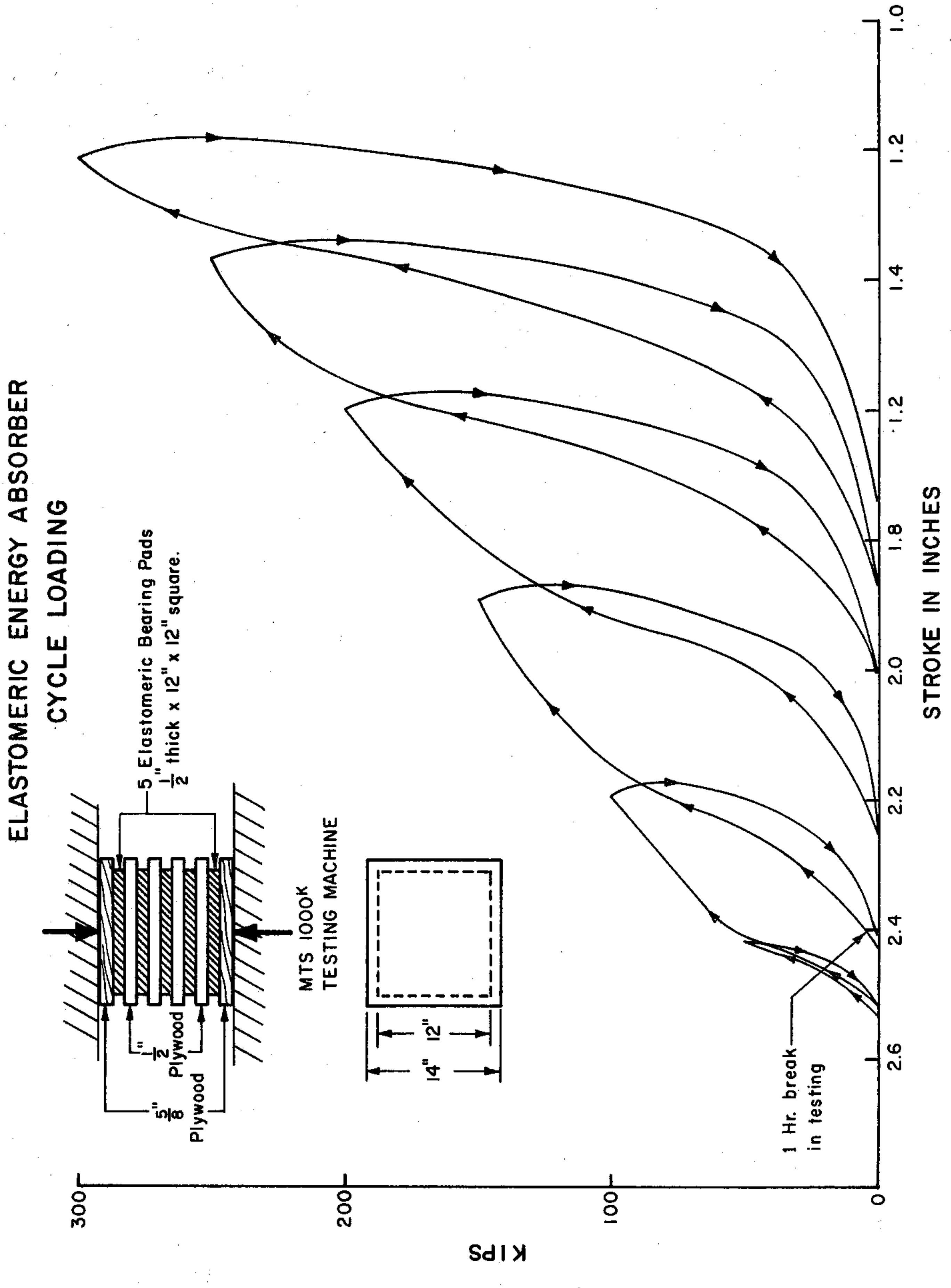


Figure 9


TEST NO. 7
ELASTOMERIC ENERGY ABSORBER
CYCLE LOADING
5 Elastomeric Bearing Pads
1/2" thick x 12" x 12" square.
1/2" Plywood
5/8" Plywood
MTS 1000K
TESTING MACHINE
14"
12"
1 Hr. break
in testing
STROKE IN INCHES
KIPS
300
200
100
0